SURFACE CHANGE DURING WARM-FORMING

By Jack Houck
February 5, 1982
Metallurgical Analysis by Victor Kerlins

During 1981, I conducted 12 "PK Parties" wherein approximately 85% of the attendies experienced metal bending with apparent ease. In general the people described a short period, typically 5 to 20 seconds, in which the metal felt warm and was extremely pliable. After this period the metal would again become hard to bend as in its normal state. We have named this phenomena "warm-forming" and have attempted to compile data which would help understand what is actually occurring. During the April 20, 1981, PK party, a 1/4" diameter steel rod appeared to dramatically change in surface color when "warm-formed" by Tim. This rod was submitted to the McDonnell Douglas Astronautics Company (MDAC) Metallurgical Laboratory for analysis, the results of which are contained in this report.

As of this writing, I have accumulated nine (9) other specimens which also appear to have a dramatic surface change when compared to their control rods. These have been warm-formed by six different individuals. In all cases, the rods and one bolt are low carbon steel, coated with zinc. Steel rods purchased in a hardware store are usually coated with zinc so that they do not rust. Not all the steel rods warm-formed at these PK Parties have the surface change occur. Those rods that do have the surface change, have it occur during the 10 to 15 minute period that it was handled by the individual that warm-formed it. Usually most of the surface color change occurs near the bend, however, in a few cases the entire rod surface changed as did the rod analysized in this report.

The results of this metallurgical analysis indicate that the surface change effect is limited to the surface of the rod. When magnified, the

surface of the warm-formed rod appears much like that of volcanic rock which diffuses light so that it appears dull as compared to the shiny surface of the control rod. A spectrual analysis of the surface indicated the presence of chlorine on the warm-form rod and none on the control rod, even though both rods were handled approximately the same amount (the warm-formed rod was handled by Tim and I handled the control rod).

Our best estimate of what happened to the warm-formed rod is that a chemical reaction occurred during the time Tim was warm-forming it. This chemical reaction could have been from either the salt (NaCl) in his perspiration forming zinc chloride (ZCl) or possibly hydrochloric acid (HCl) in his perspiration forming ZCl. Further analysis is required to determine if either of these chemical reations will cause the surface appearance and if so, under what conditions (e.g., temperature, pressure, amount of perspiration, etc). It is again pointed out that this surface change does not always occur when these zinc coated steel rods are handled and even warm-formed by many individuals. Does the rod become exceptionally hot for some people, thus facilitating the chemical reaction? This question has led to the desire to instrument some rods during the warm-forming process to determine the temperatures involved. Or do a few people have a very high PH factor in their perspiration?

During the December 16, 1981 PK Party, several rods were bent by warm-forming and indicated the surface change. On each of the rods I had placed an identification tag attached to the rod with clear tape. These tags allow me to find the correct control rod. On several of the specimens obtained at this party, the surface change encompassed the area where the tape covered the surface of the rod. When I peeled back the tape to see if the rod surface changed under the tape, I found that underneath the surface was still shiny--no change. This reinforces the idea that this change results from a chemical reaction between something on the hands or in the perspiration of the individual performing the warm-forming.

Prior to the April 20, 1981, "PK Party", I prepared a number of steel rods to be warm-formed. The rod discussed herein is 12" long and 1/4" in

diameter, made of 1018 steel, coated with zinc, and was purchased at a local hardware store. Masking tape and the price sticker on the rod at the time of purchase left a sticky gum which I removed by applying gasoline to the entire rod. I then rubbed the entire rod with 0000 steel wool to make it shiny and clean. Then I cut the rod into three sections, one was kept in my den as a control and the other two were available for warm-forming at the party. I filed the ends so that no one would be cut. Tim took one of these rods and warm-formed it during a period of approximately 15 minutes. He noted that when the rod became warm and was easily malleable, a permanent color change occurred over the entire surface of the rod (not just where the bend occurred). This seemed to be clear evidence that something happened to the rod that could not be explained by physical force. The warm-formed rod and its control rod were submitted to the MDAC Metallurgical Laboratory for a Scanning Electron Microscope (SEM) analysis of the surface of both specimens. A small section was cut off the end of the straight (control) rod in order to fit it into the SEM. Figure 1 shows both the straight and the warm-formed rods.

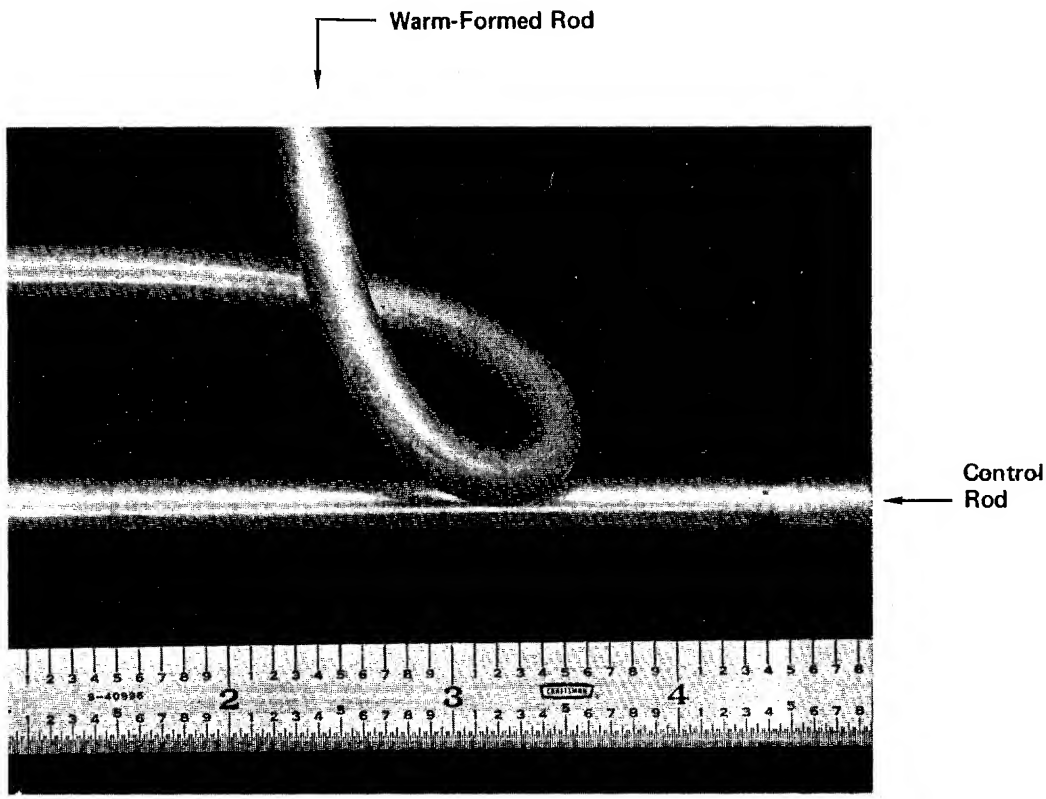


Figure 1. Apparent Surface Color Difference Between Control and Warm-Formed Rods

Figure 2 shows the surface of the straight rod magnified 15 times by the SEM. Two areas were selected for further magnification; marked 1 and 2. Figures 3 and 4 show Area 1 of the straight rod magnified 1.15K and 7.8K times, respectively. The scratches were caused by the steel wool and some typical surface pitting can be observed. The high magnification was difficult to obtain and some gold coating was required to achieve sufficient electron densities. Similarly, Figures 5 and 6 show Area 2 of the straight rod magnified 1.16K and 7.9K times, respectively. The surface at Area 2 is very similar to that of Area 1. Nothing is unusual about the surface of the straight rod.

Figure 7 shows the surface of the warm-formed rod, magnified 23.7 times looking directly at the end (outside region of maximum curvature). Two areas were again selected for further magnification; marked 1 and 2.

Figures 8 and 9 show Area 1 of the warm-formed rod magnified 1.18K and 8.1K times, respectively. The surface appears dramatically different from that of the straight rod. These pictures are the result of patterns established by the surface reflection of the electrons in the SEM. Because the surface appears to have been drastically altered, one would suspect that the dull appearance to the naked eye is caused by the light scattering and being diffused by this highly irregular surface. Also note that extremely high magnifications were obtained with no difficulty, suggesting the electrical conductivity of the surface is very high. Figures 10 and 11 show Area 2 of the warm-formed rod magnified 1.2K and 12K times respectively and are very similar to the surface in Area 1.

The results of this testing prompted many questions. One question was: "Does a straight section of the warm-formed rod illustrate the same apparent change on the surface?" To the naked eye, the straight section of the warm-formed rod appeared to have the same type of dull surface as was apparent on the bent portion of the rod. However, to answer this question, a section of the straight portion of the warm-formed rod was cut and examined with another section of the control rod. Figure 12 shows where the straight section was taken from the warm-formed rod. (The photograph was taken prior to the

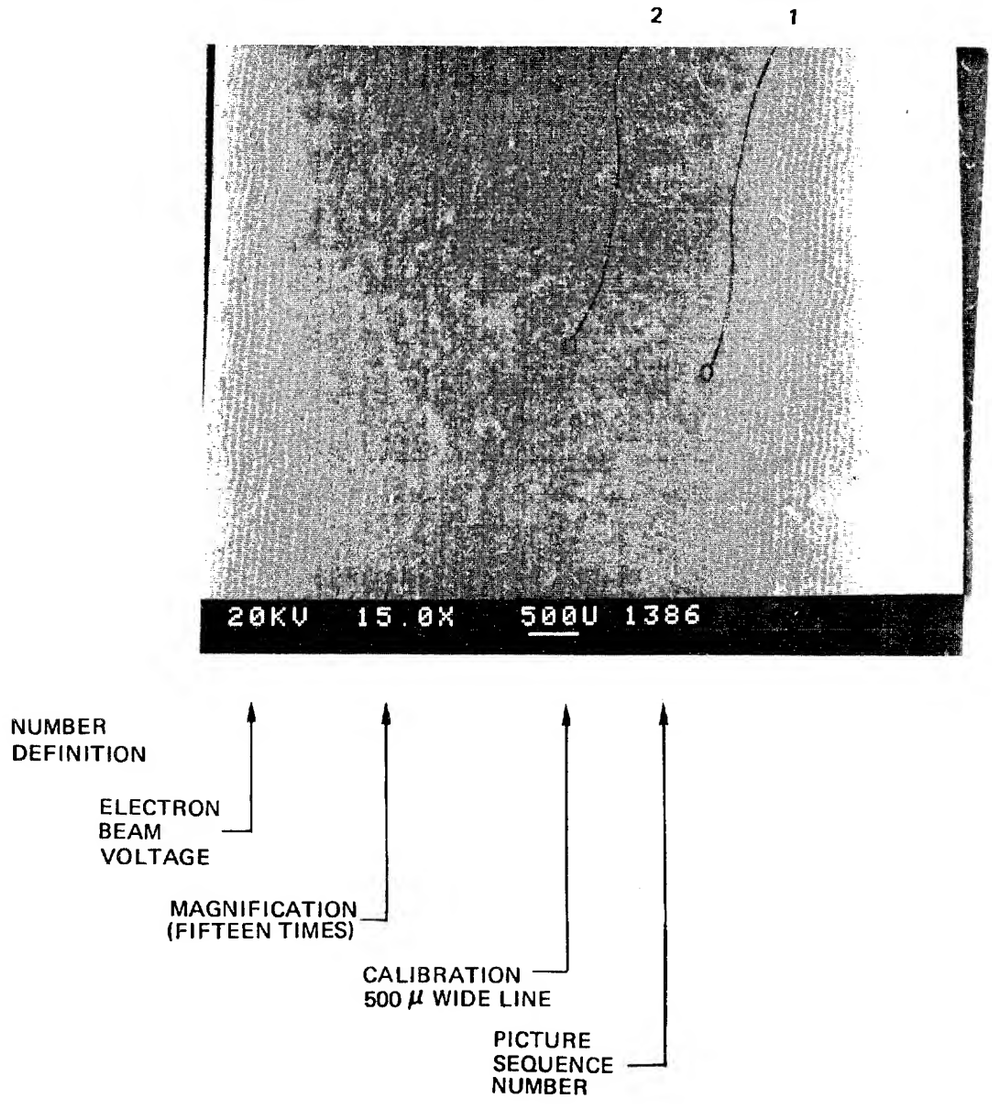


Figure 2. Surface of Control Rod At Bend (15X)

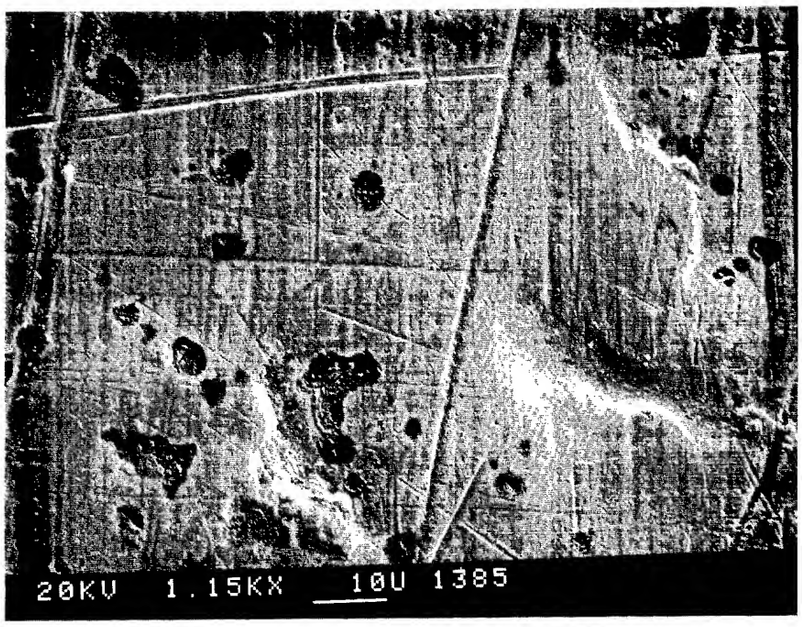


Figure 3. Surface of Control Rod At Area 1 (1.15KX)

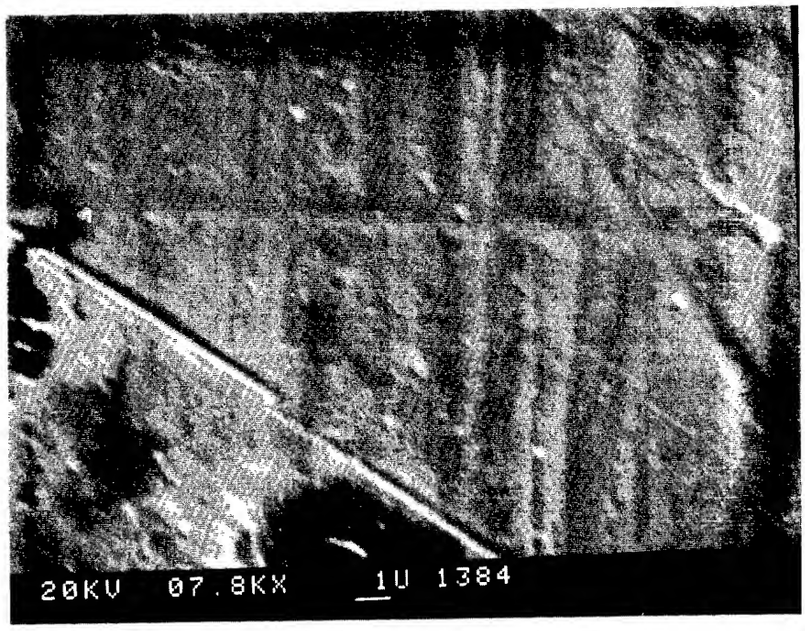


Figure 4. Surface of Control Rod At Area 1 (7.8KX)

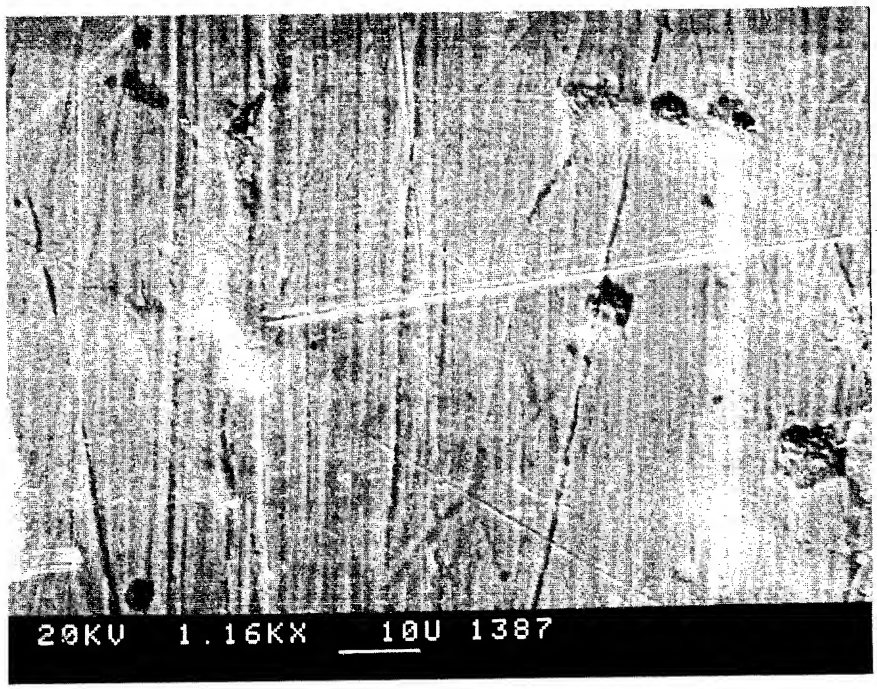


Figure 5. Surface of Control Rod At Area 2 (1.16KX)

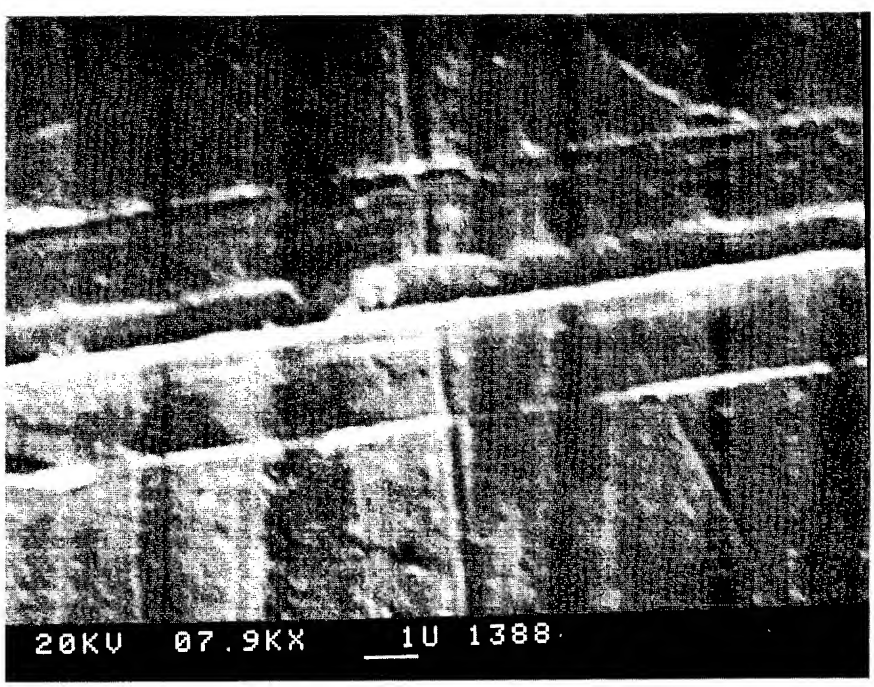


Figure 6. Surface of Control Rod At Area 2 (7.9KX)

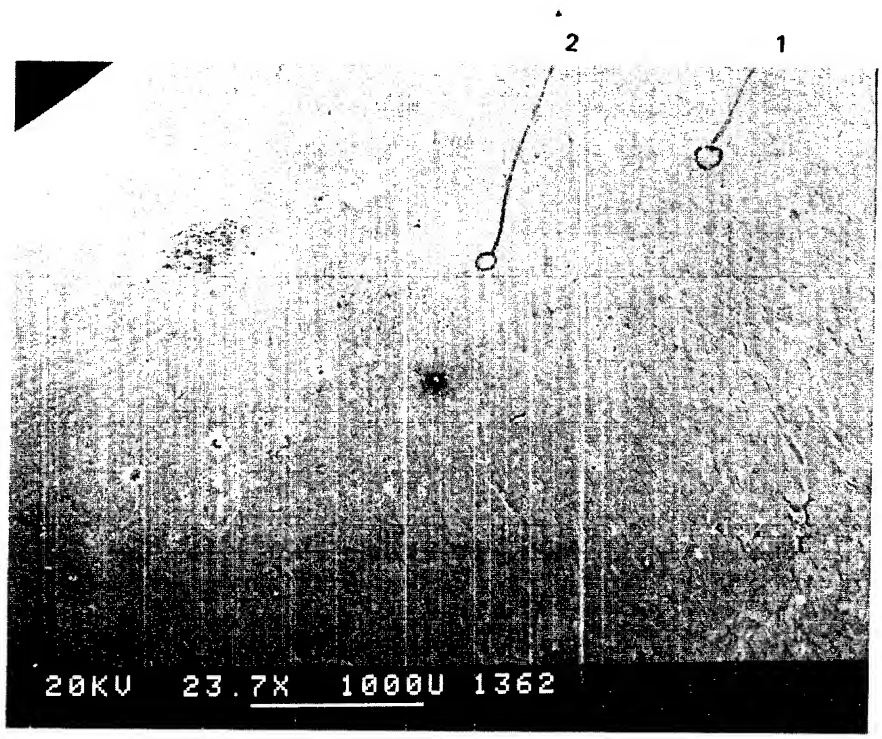


Figure 7. Surface of Warm-Formed Rod At Bend (23.7X)

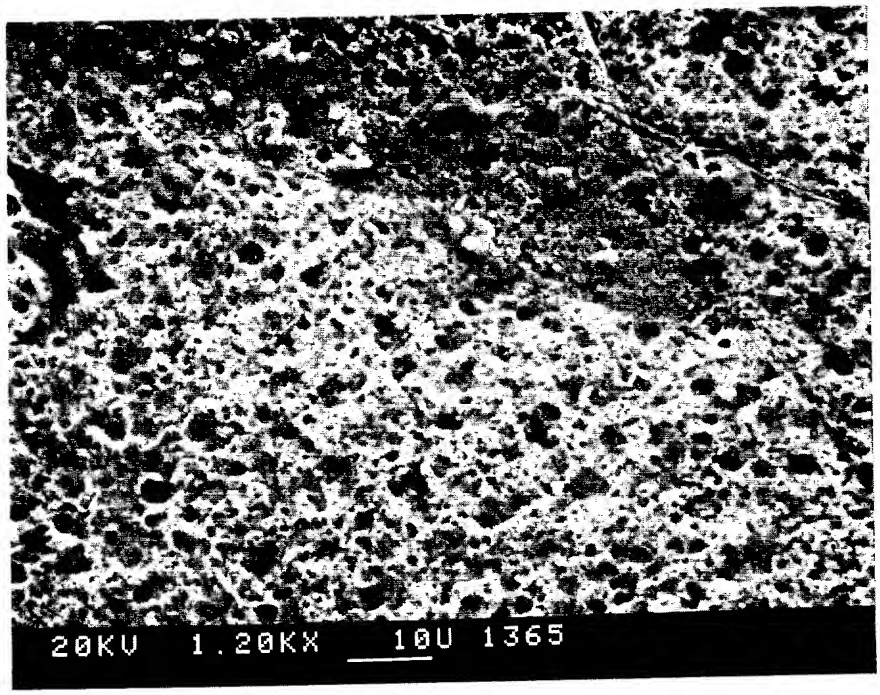


Figure 10. Surface of Warm-Formed Rod At Area 2 on Bend (1.2KX)

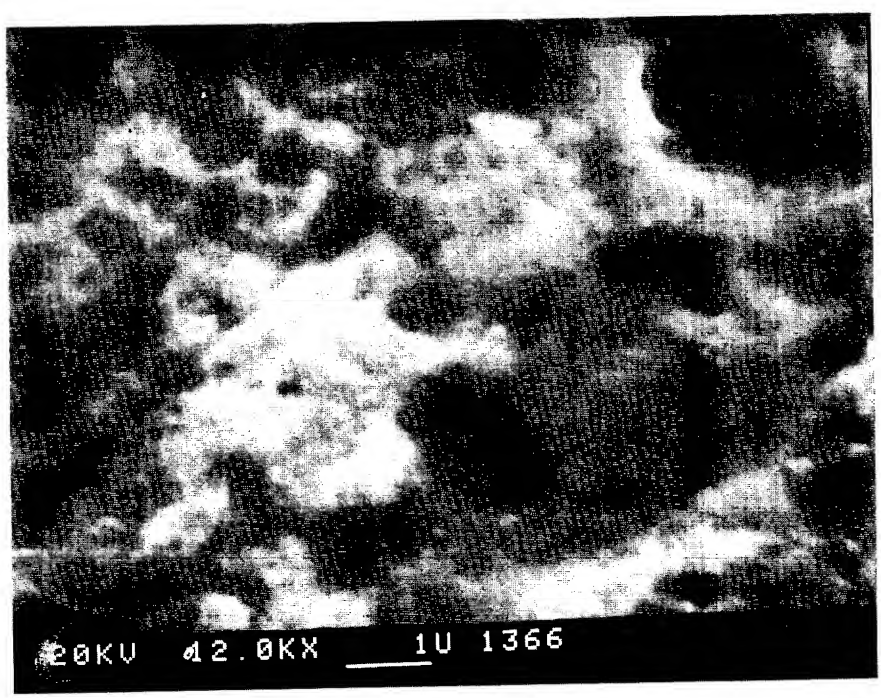


Figure 11. Surface of Warm-Formed Rod At Area 2 on Bend (12KX)

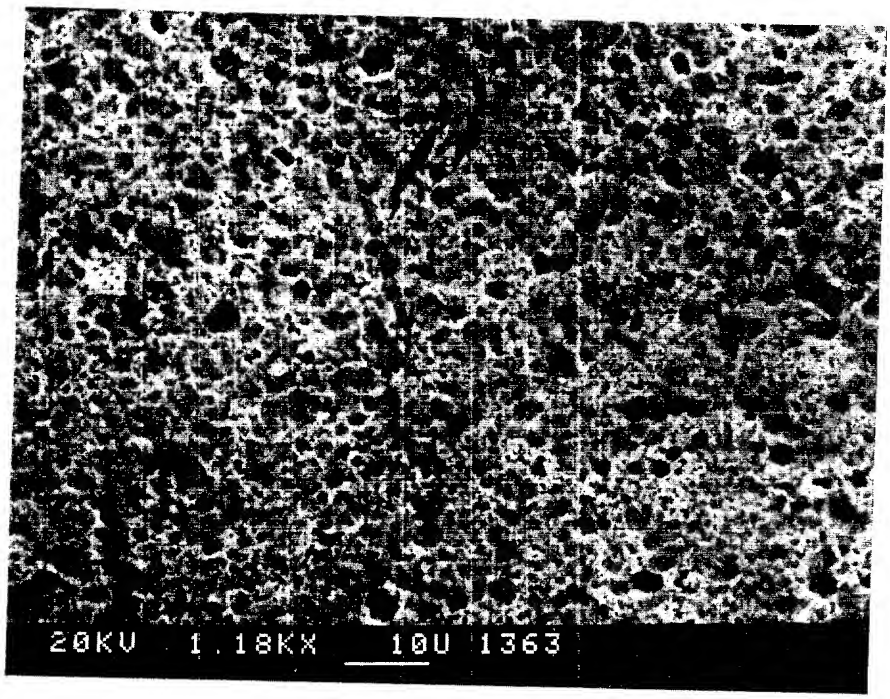


Figure 8. Surface of Warm-Formed Rod At Area 1 on Bend (1.18KX)

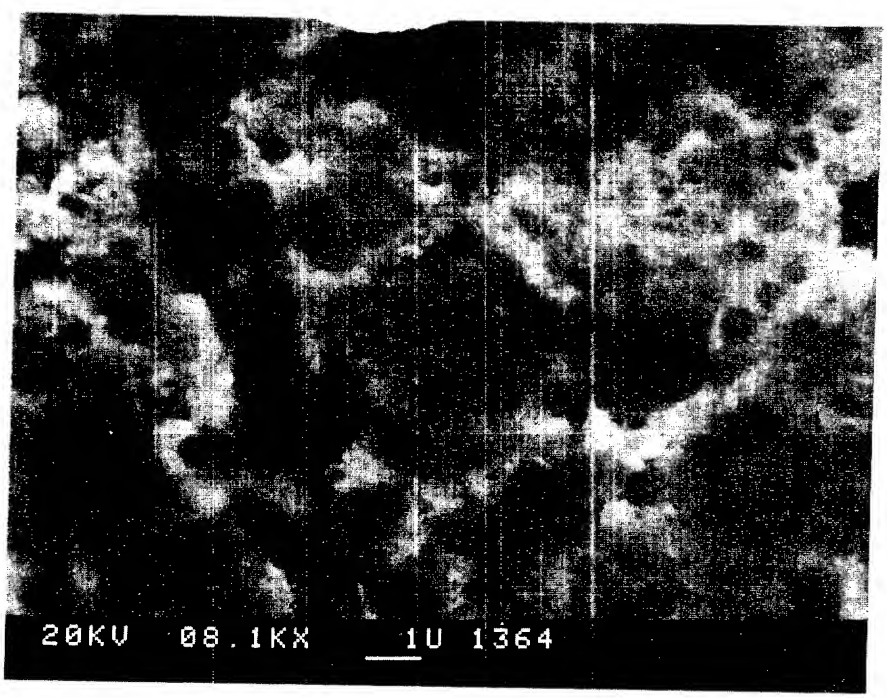


Figure 9. Surface of Warm-Formed Rod At Area 1 on Bend (8.1KX)

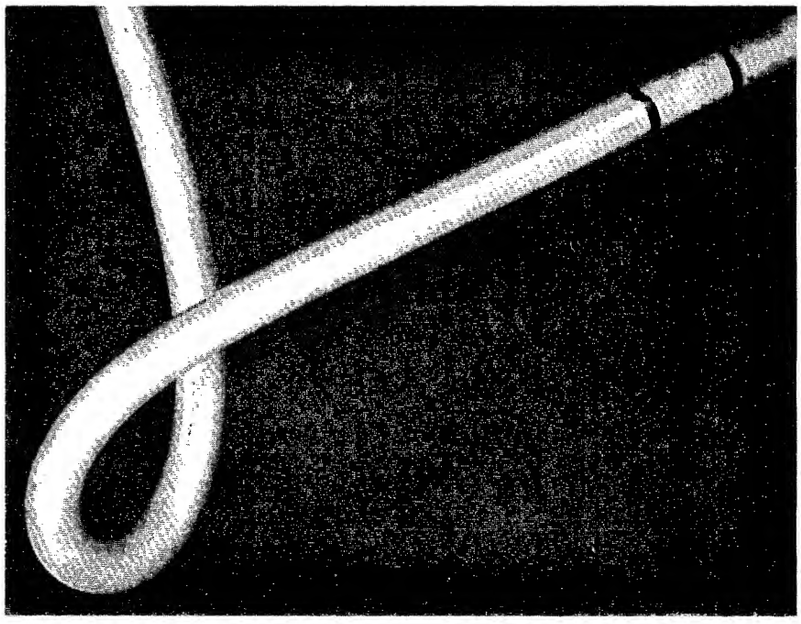


Figure 12. Section Cut For Analysis From Warm-Formed Rod

section being removed.) Figure 13 shows the surface of the control rod section magnified 14.3 times. Figure 14 shows the same section magnified 98 times. Further magnification (520 times) of that same section is shown in Figure 15. Points A and B are defined in Figure 15 by the arrows on the margin. Magnification of point A to 2.76 times is shown in Figure 16. Similarly, magnification of point B to 2.78K times is shown in Figure 17. These photographs of another portion of the control rod surface are essentially identical to those previously shown in Figures 2 through 6. The surface of the straight section removed from the warm-formed rod, magnified 14.3 times, is shown in Figure 18. Figure 19 shows that same section magnified 97 times. Further magnification (520 times) is shown in Figure 20. New points A and B are defined by the arrows shown in the margin on Figure 20. Further magnification of point A is shown in Figure 21, magnified 2.78K times. Similarly a magnification of 2.78K times of point B is shown in Figure 22. It can be seen that the surface of the straight portion of the warm-formed rod is very similar to the surface of the bent portion shown in Figures 7 through 11. Thus, the SEM shows that the same type of surface pitting occurred over the entire warm-formed rod.

In attempt to further understand what happened to the surface of this rod when warm-formed, an energy dispersive X-ray diffraction analysis was performed. Figures 23 and 24 show the spectral lines resulting from that analysis for the control and warm-formed rod, respectively. The peaks are predominantly the 3 zinc (Zn) lines, an iron (Fe) line, and a chlorine (Cl) line. The zinc and iron lines are essentially identical on both spectrums. However, a strong chlorine occurred on the spectrum of the warm-formed rod. It is postulated that the source of the chlorine might be from salt (NaCl) which is contained in perspiration from the hands during warm-forming. The sodium (Na) line would have occurred at 1.04 Å and would essentially be swamped by the smallest zinc line which occurs at 1.1 Å. As indicated earlier, Tim handled the warm-formed rod for only approximately 15 minutes, and I do not know if his hands were perspiring. However, the total amount of handling of both rods by human hands is probably nearly identical, because I carried both rods around the country prior to analysis and often handled the control rod. However, my hands were probably not perspiring when handling

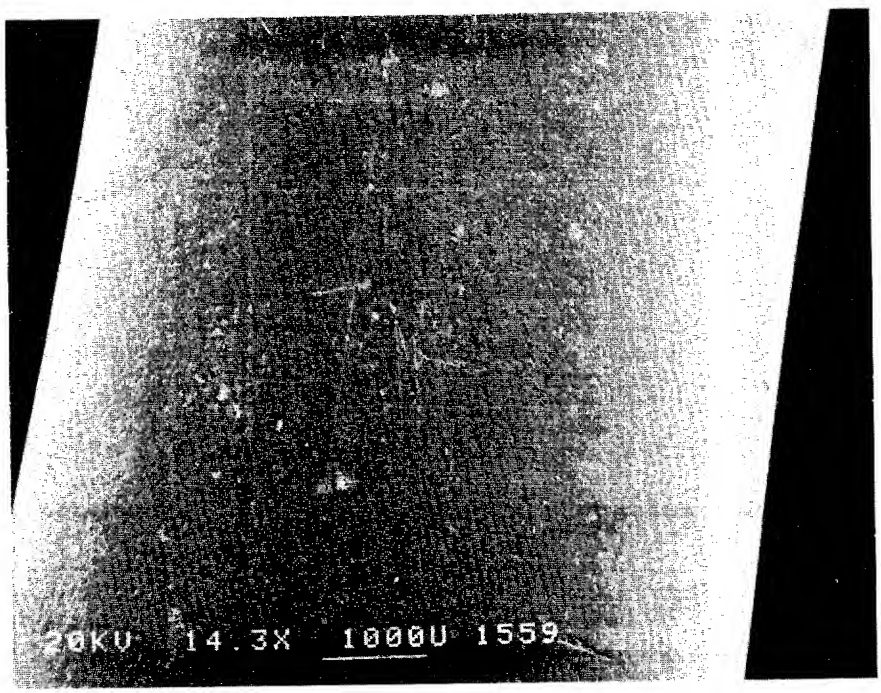


Figure 13. Surface of Control Rod (14.3X)

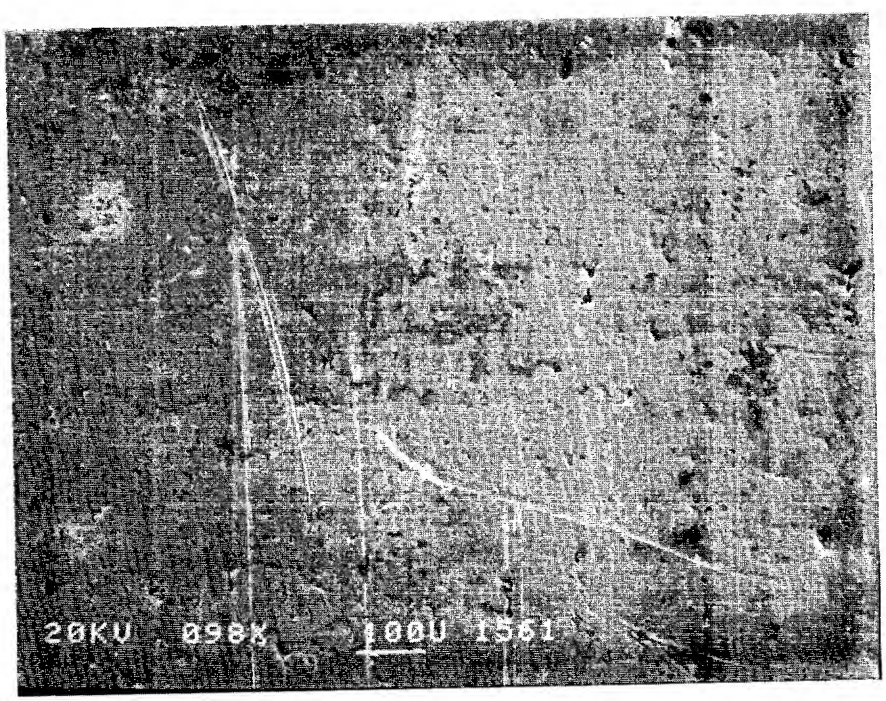


Figure 14. Surface of Control Rod (98X)

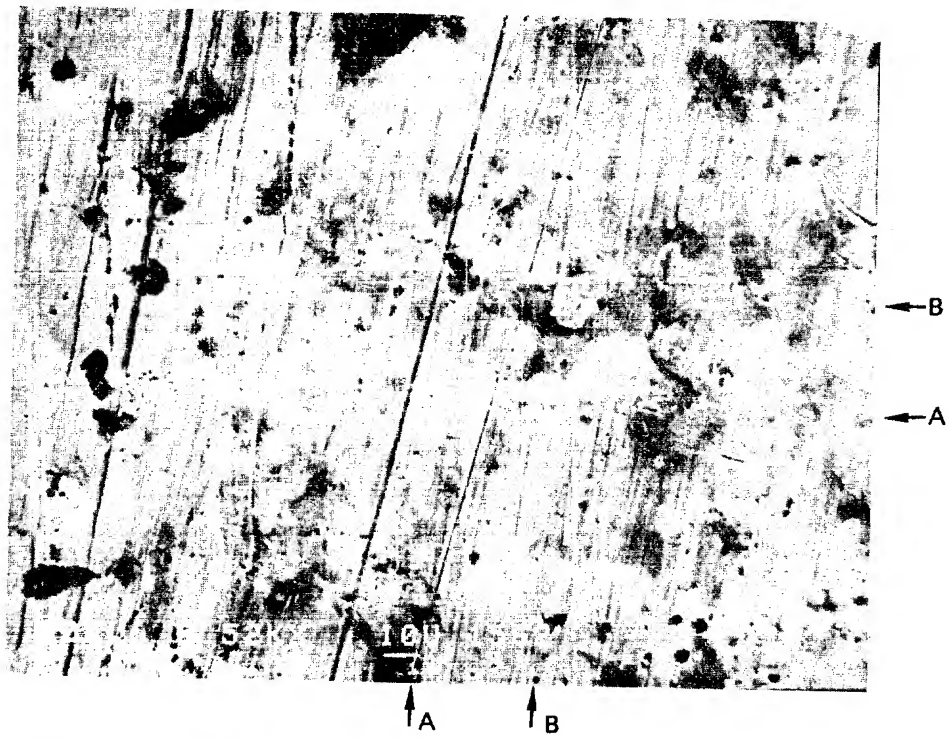


Figure 15. Surface of Control Rod (520X)

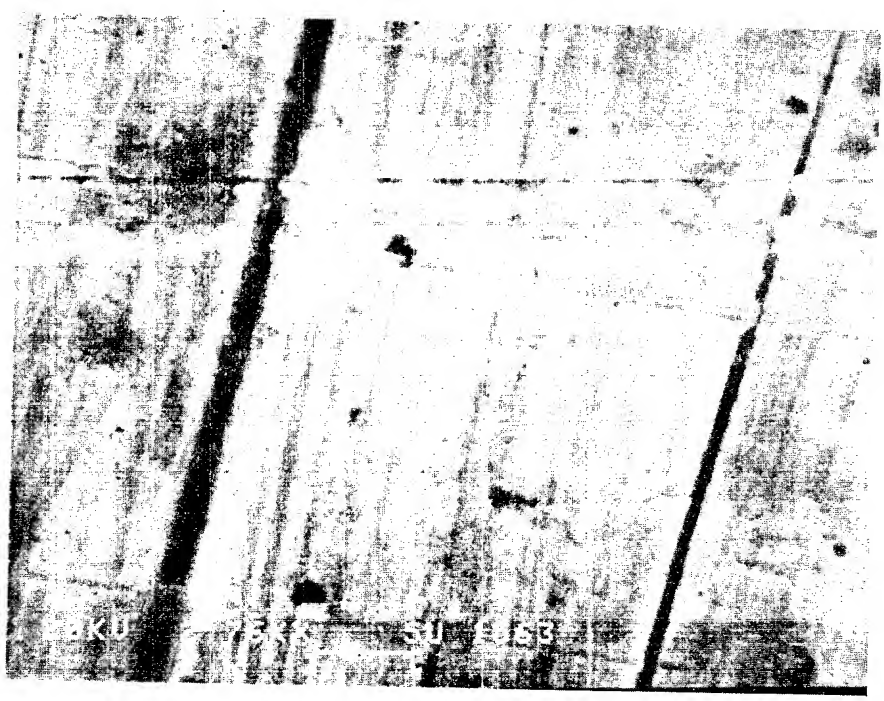


Figure 16. Surface of Control Rod, Area A (2.76KX)

Figure 17. Surface of Control Rod, Area B (2.70KX)

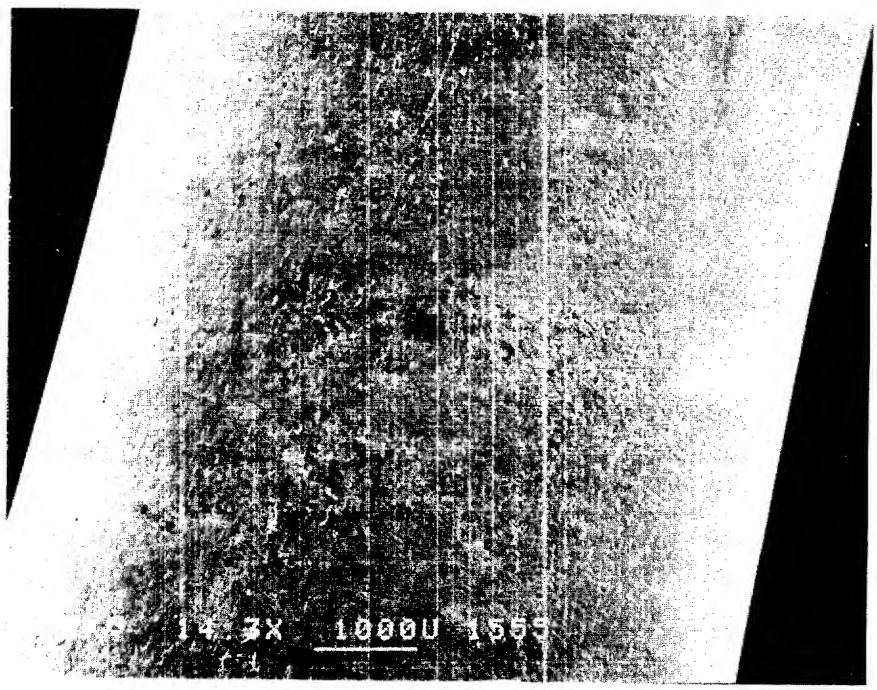


Figure 18. Surface of Warm-Formed Rod in Straight Section (14.3X)

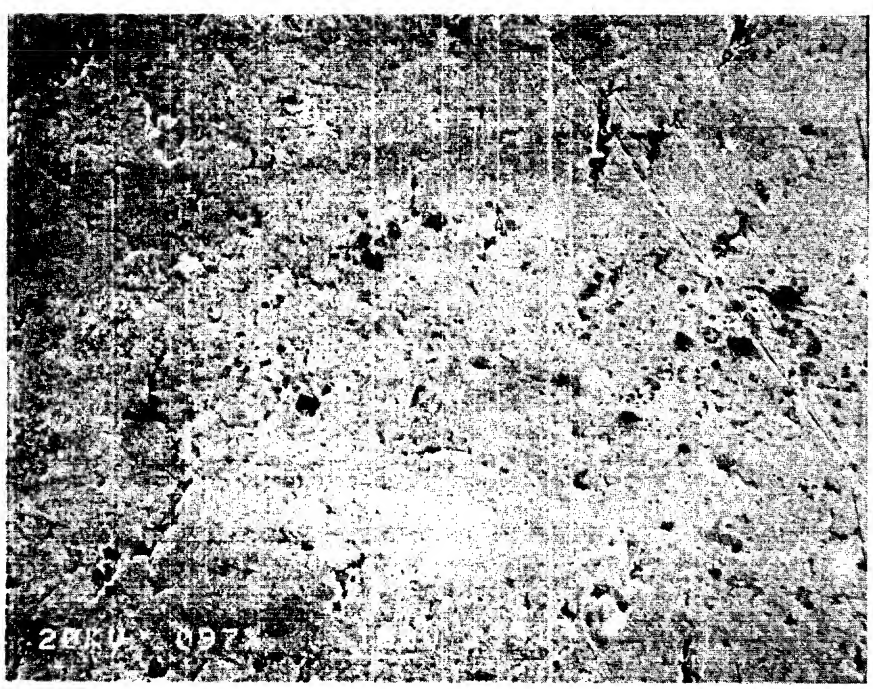


Figure 19. Surface of Warm-Formed Rod in Straight Section (97X)

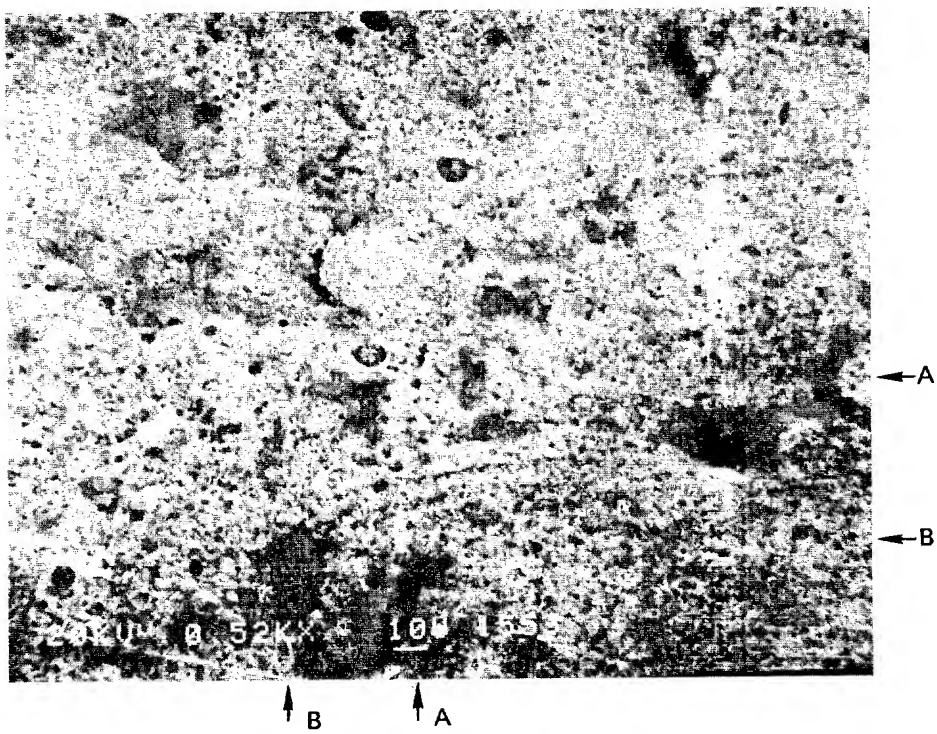


Figure 20. Surface of Warm-Formed Rod in Straight Section (520X)

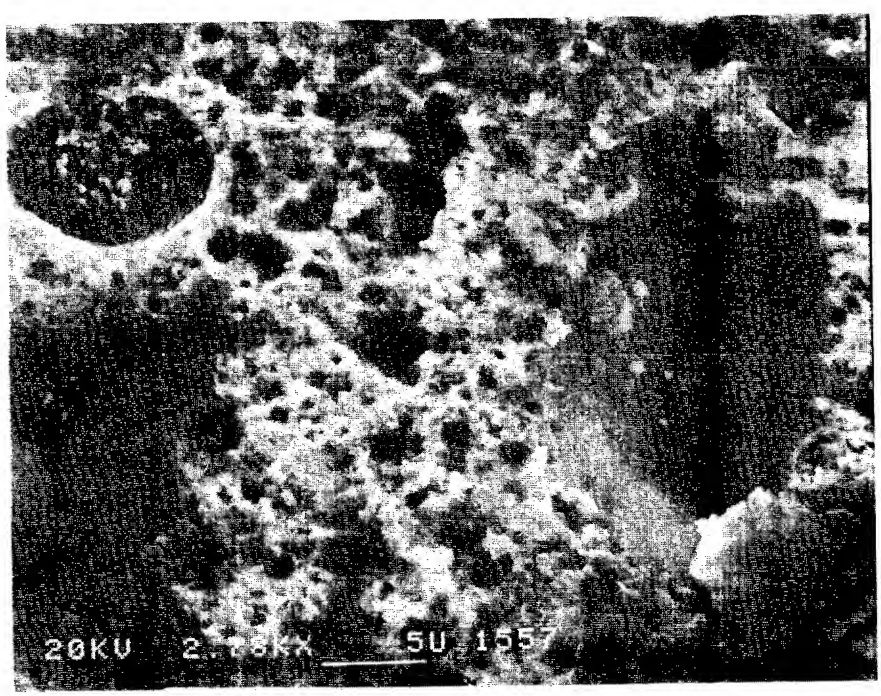


Figure 21. Surface of Warm-Formed Rod in Straight Section, Area A (2.78KX)

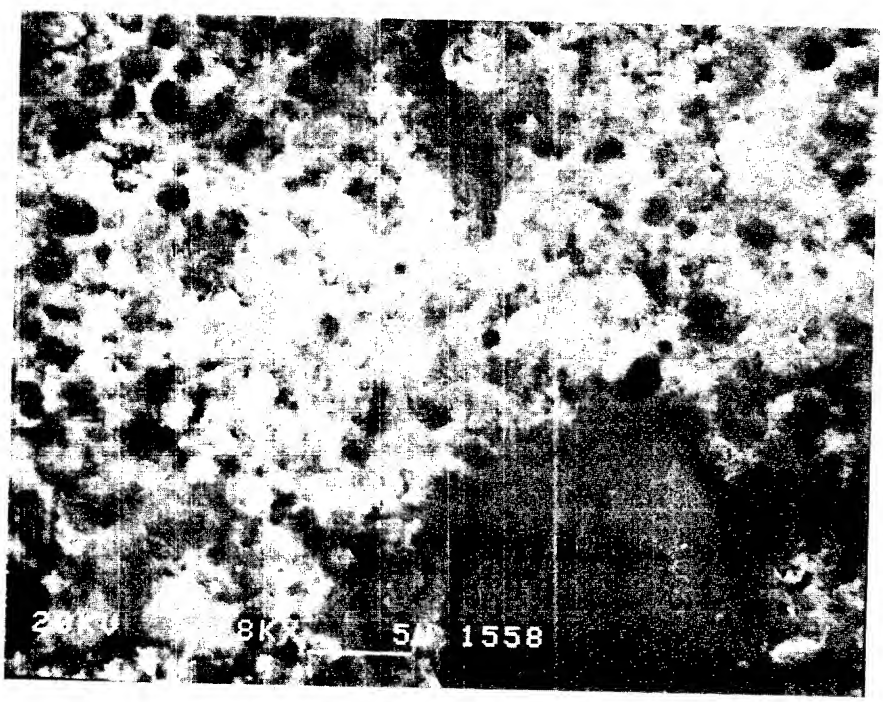


Figure 22. Surface of Warm-Formed Rod in Straight Section, Area B (2.78KX)

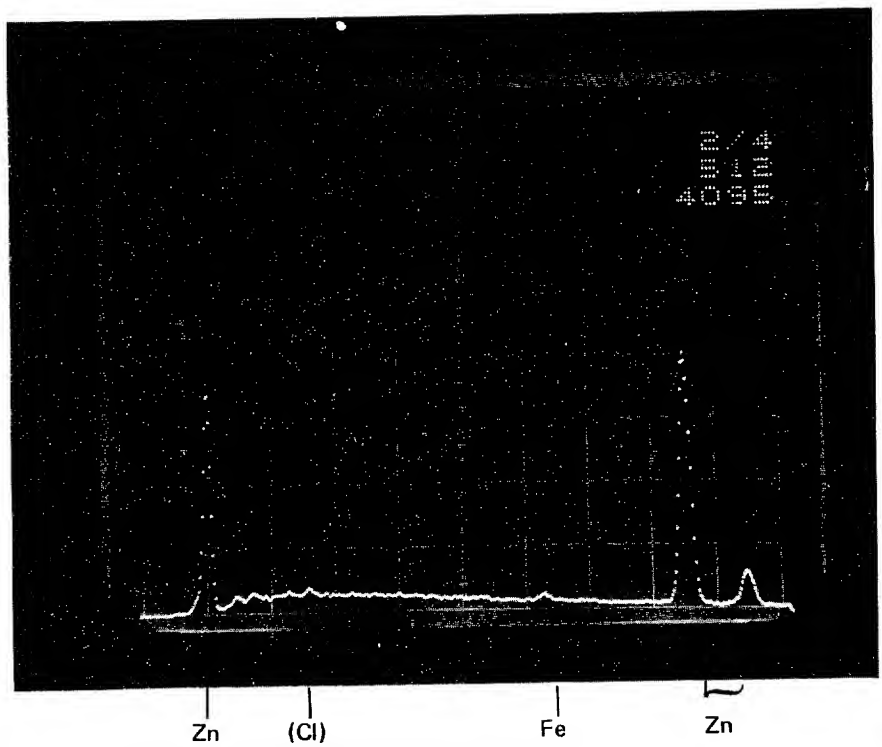


Figure 23. Spectrual Lines of Control Rod Surface

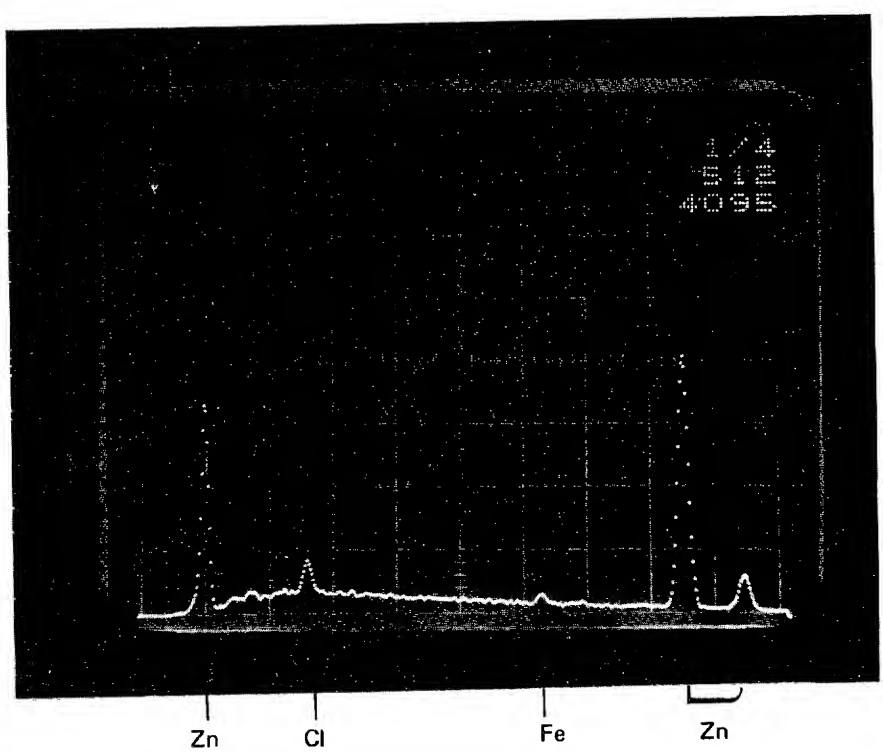
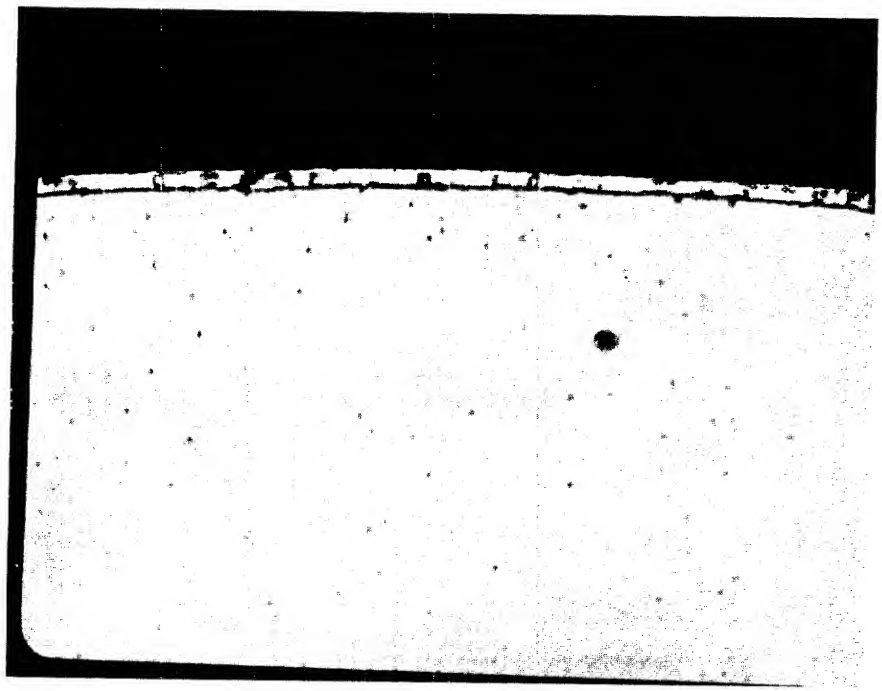
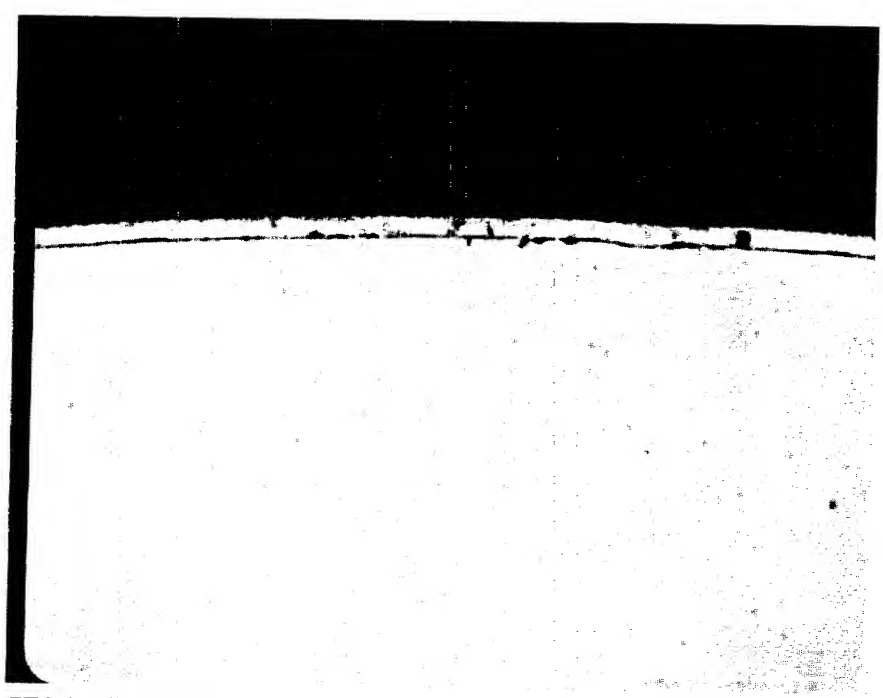


Figure 24. Spectrual Lines of Warm-Formed Rod Surface, Straight Section



ETCHANT: NITAL MAG: 250X

Figure 25. Cross-Section of Control Sample



ETCHANT: NITAL MAG: 250X

Figure 26. Cross-Section of Warm-Formed Sample

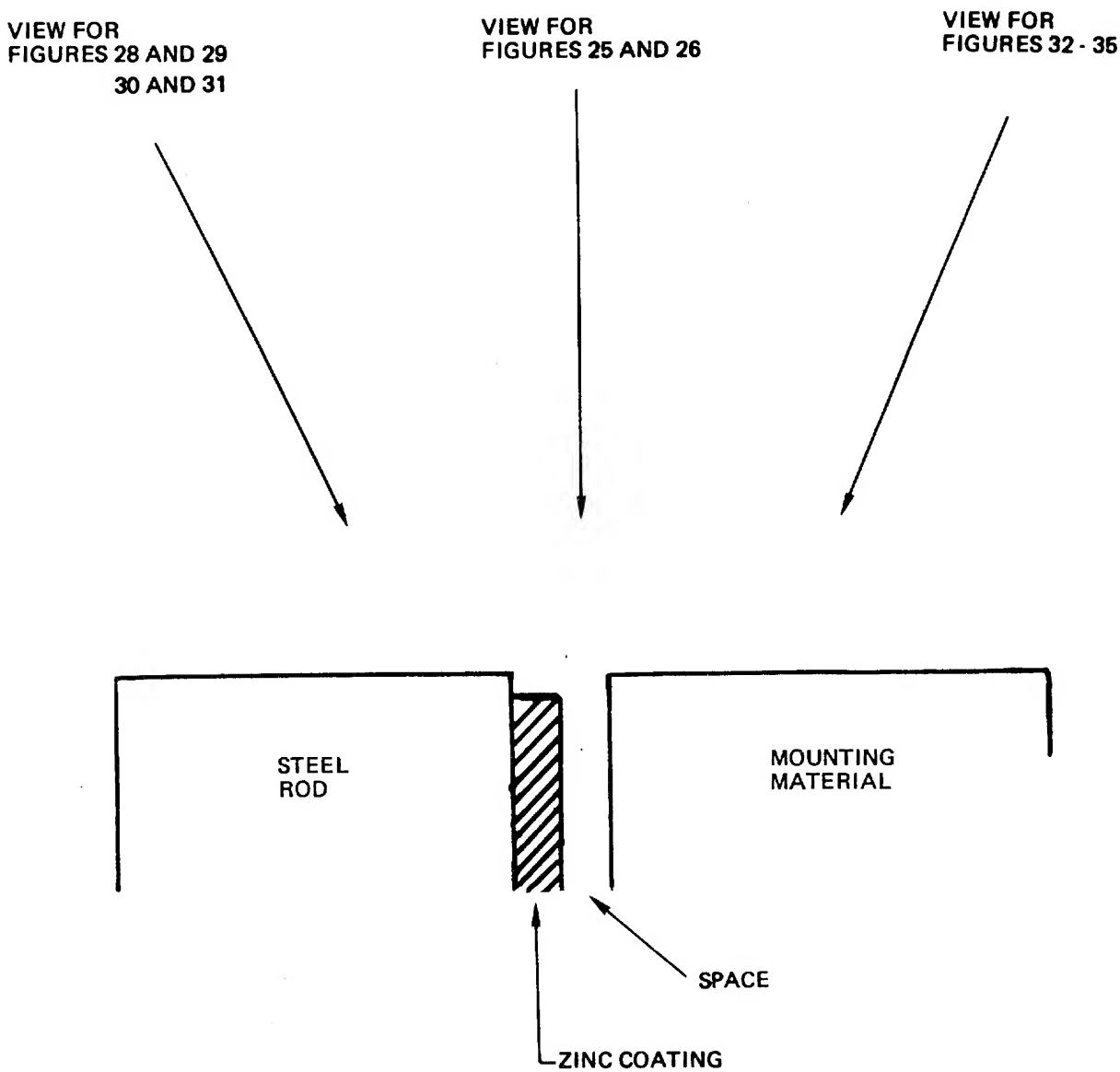


Figure 27. Side View of Mounting

the rod. Another possibility to explain the chlorine line is that zinc chloride ($ZnCl_2$) may have been formed if hydrochloric acid (HCl) was present in the sweat of Tim's hands. However, this is not common.

$$Zn + 2Hcl = Zn\ Cl_2 + H_2\uparrow$$

Next, a cross section was taken from both the control and warm-formed rods and mounted for an X-ray map examination. These sections were polished and mildly etched using a 2% NITAL solution which rapidly affects the zinc. The control and warm-formed cross sections are shown magnified 250 times in Figures 25 and 26, respectively. These photographs were taken looking directly down at the cross section. They clearly show the zinc coating over the steel rod. The steel is to the bottom of both photographs and the mounting material is at the top of both photographs. There is a small space or gap between the mounting material and the zinc coating. If one were to look across the edges of the specimens, the view would appear like that shown in Figure 27. The etching removed a bit of the zinc coating causing the slight step as shown in Figure 27. The purpose of the X-ray map examination was to determine if any zinc had penetrated into the steel case of the rod. Figures 28 and 29 show the optical picture, magnified 1,000 times, for the control and warm-formed specimens, respectively. It can be seen that zinc did not penetrate into the steel (bottom) on either specimen. Figures 30 and 31 are the zinc X-ray maps of the control and warm-formed specimens, respectively. The very dense band (top left to bottom right) shows the concentration of zinc in the zinc coating. The less dense band, directly above results from reflections in the mounting space. It can be seen that these X-ray maps are essentially identical, further indicating no penetration of the zinc along the grain boundaries of the steel rod.

In Figures 32 through 35, the zinc coating was viewed looking toward the iron rod (see Figure 27 for perspective). Figures 32 and 33 show this view magnified 248 times for both the control and warm-formed samples, respectively. This same view, magnified 2.49K times is shown in Figures 34 and 35 for the control and warm-formed samples, respectively. A thin coating on the surface of the zinc plate can be seen clearly. The surface change seems to be only on the immediate surface of the warm-formed rod. This may be a thin layer of ZnCl on the surface which appears to have increased or been modified by the warm-forming process.

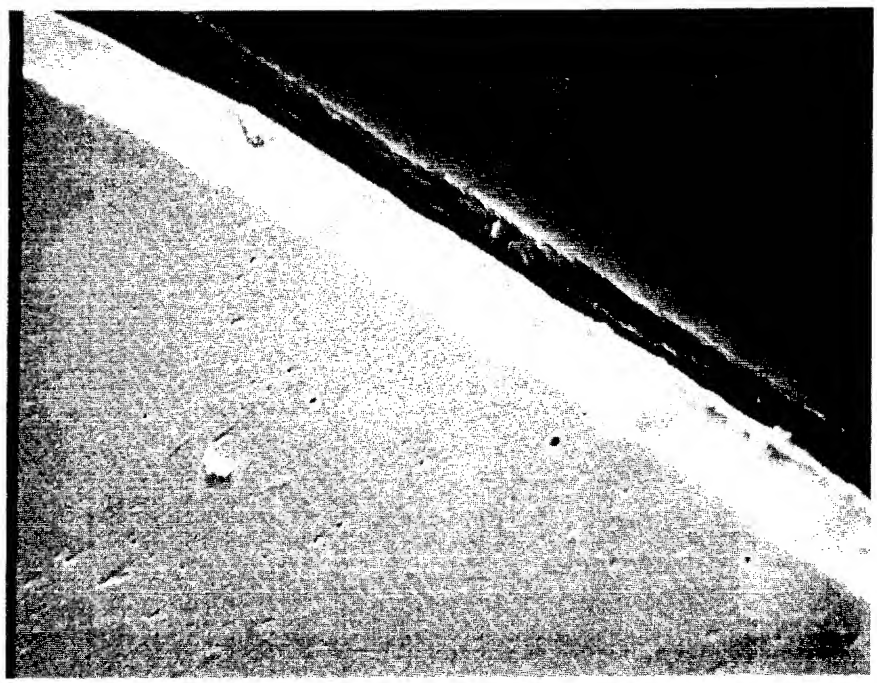


Figure 28. SEM Micrograph of Cross-Section of Control Rod (1000X)

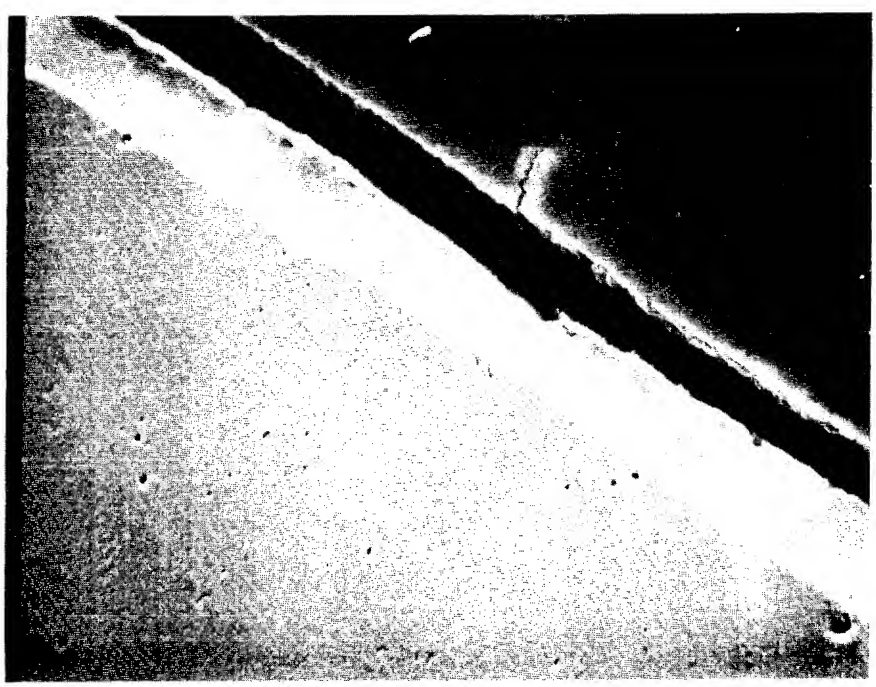
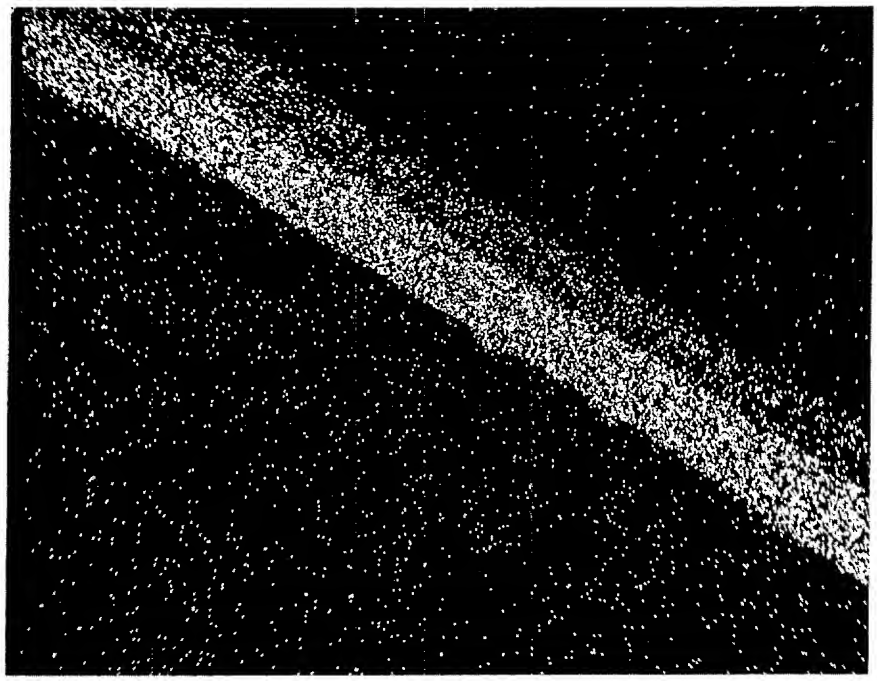


Figure 29. SEM Micrograph of Cross-Section of Warm-Formed Rod (1000X)



MAG: 1000X

Figure 30. SEM-X Zinc X-ray Map of Control Cross-Section

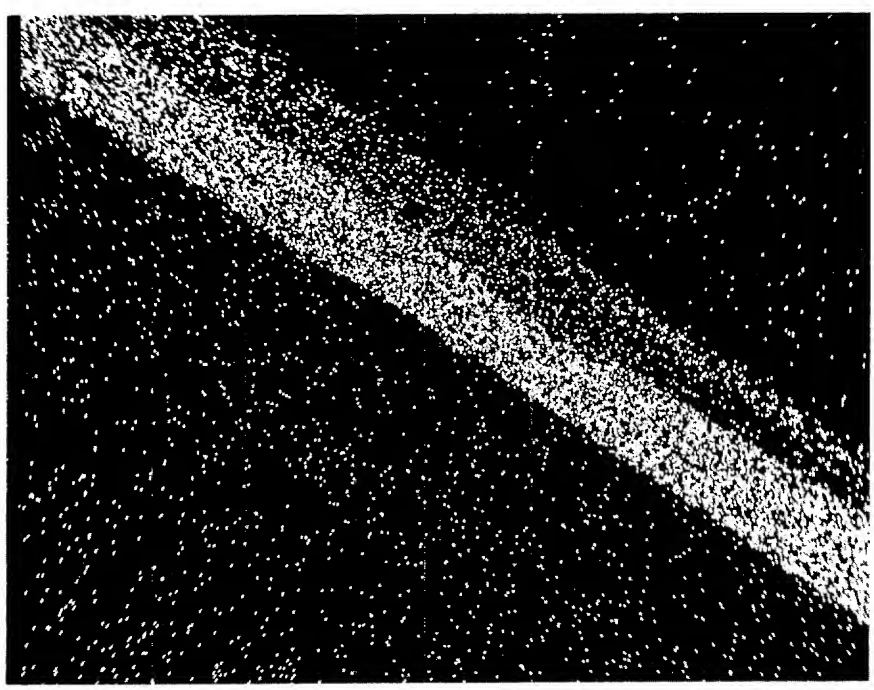


Figure 31. SEM-X Zinc X-ray Map of Warm-Formed Cross-Section

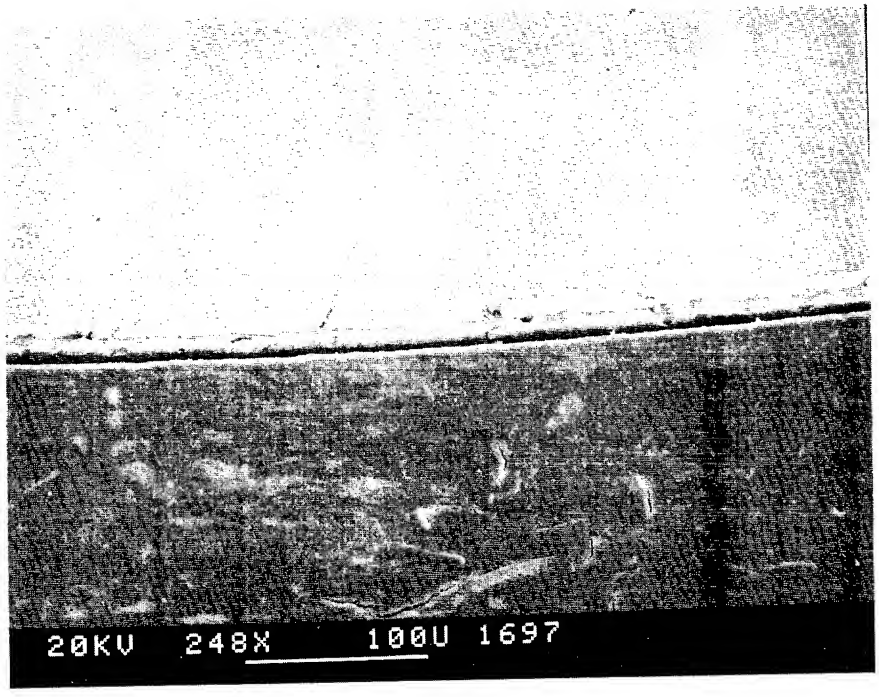


Figure 32. Alternate View of Control Cross-Section (248X)

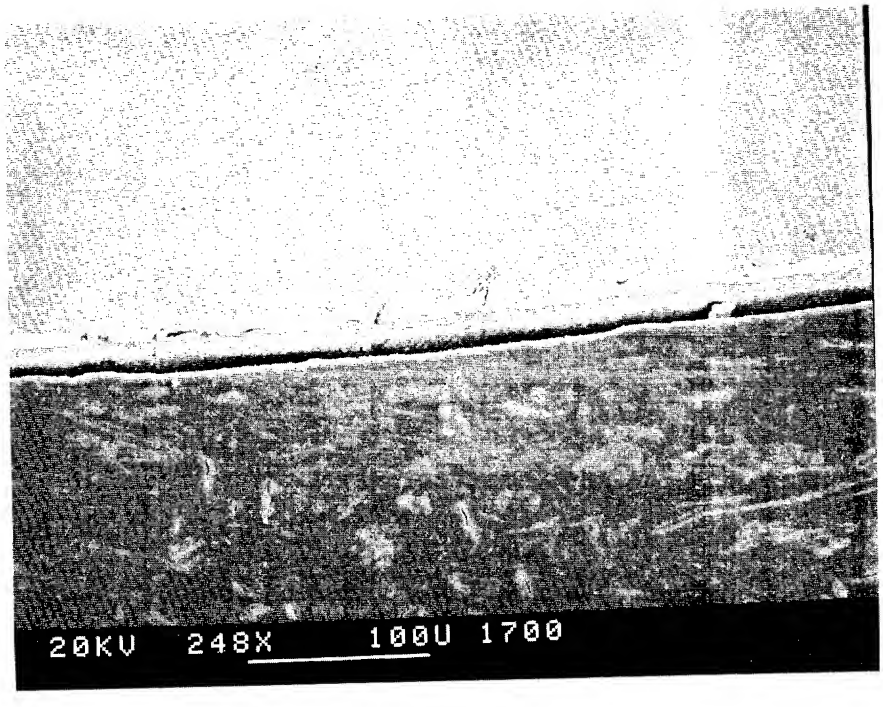


Figure 33. Alternate View of Warm-Formed Cross-Section (248X)

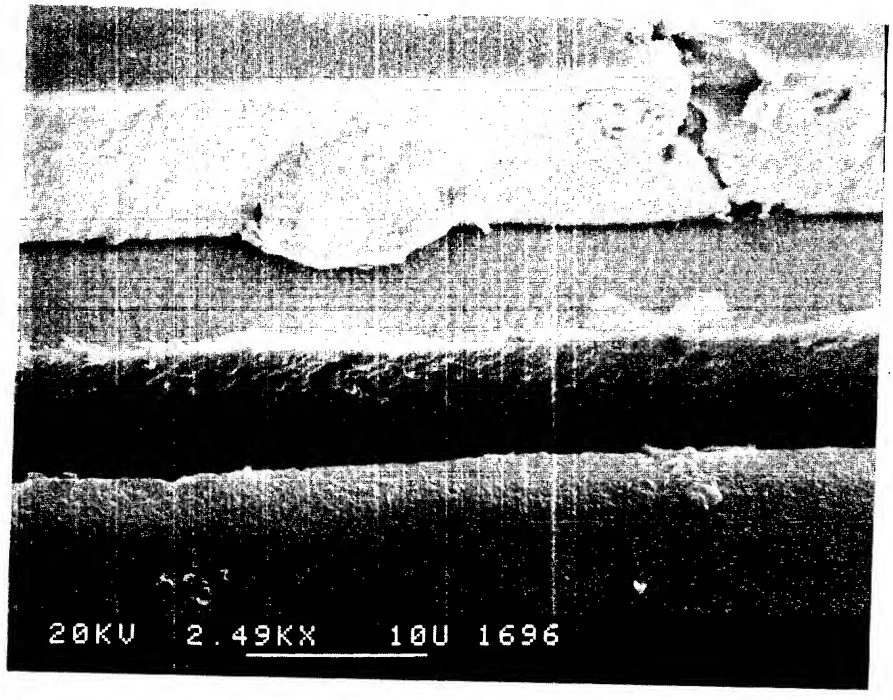


Figure 34. Alternate View of Control Cross-Section (2.49KX)

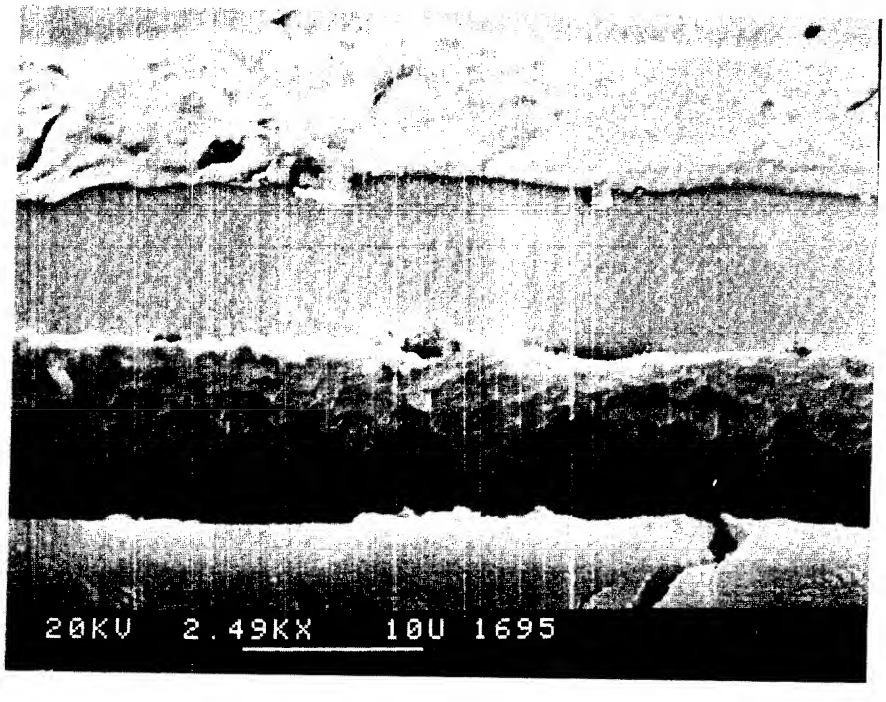


Figure 35. Alternate View of Warm-Formed Cross-Section (2.49KX)

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